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Environmental evaluation of recycling technology and the impact of the transport of Aluminum cables

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Abstract

The goal of this study is to document the environmental impact of a recycling aluminum process, using the Life Cycle Assessment (LCA) methodology, in accordance with the standards of International Organization for Standardization (ISO 14040/44). Today, the life cycle impact of European generic primary and secondary aluminum are well defined through the work of the European Aluminum Association (EAA). However specific recycling processes are not available in literature.
In this study, the environmental assessment of cable recycling processing is examined. The data come from a recycling plant (MTB Recycling) in France. The specific and innovative process was developed by MTB Recycling engineers and is sold as a process solution in different countries. The specificity of MTB process relies on the absence of fusion for metal refining. Nevertheless, it reaches standard aluminum purity up to 99.6%. This performance is obtained using only mechanical separation and optical sorting processes on shredder cables.
Environmental impact assessment is done using ILCD Handbook recommendations. On the one hand, the study demonstrates huge environmental benefits for aluminum recycled in comparison with primary aluminum. On the other hand, the results show the harmful environmental influence of the heat refining by comparison with cold recycling process.

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Keywords: Recycling ; Life Cycle Assessment ; Transport impacts evaluation ; Aluminum cables

1. Introduction and context

The rise of the world population and its life conditions go hand in hand with the growth of energy and raw material consumption as well as the steadily growing CO2 concentration in the atmosphere [1, 2]. The consumption growth comes by an increase in the amount of waste produced annually [3, 4]. The demand for primary resources is not sustainable long term [5]. Thus, it is vital to find industrial solutions to maintain standards of living equivalent while also decoupling resource use and demand [6]. The circular economy offers a partial answer to solve the problem [7]. Industrial companies are developing recycling solutions in close loop [8]. Recycling is inseparable from

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circular economic strategies. Although product centered End-of-Life (EoL) solutions using recycling show good environmental performance results; this paradigm shift is primarily motivated by economic considerations [9–11]. A specific EoL requires a suitable and efficient logistics system to reach the recycling plant.

Large technical systems (such as telecommunication, power and water supply systems) have been constructed and maintained in order to remain in service for long periods of time [12, 13]. These systems largely use metals such as aluminum, copper, lead, steel, zinc, etc. Depending on the applications the metals used to have a high purity, they can therefore easily replace primary resources after recycling [12, 14, 15].

From an economic point of view, deposits are important during the deconstruction phases. In fact, separate collection is warranted to maintain the value of these metals. The cable industry mainly uses aluminum and copper for theirs electrical and weight properties [16]. To obtain optimal electrical conductivity, metals use for cables has purity above 99.7% for aluminum and 99.8% for copper [17]. Secondary aluminum does not meet the quality requirements; then cable manufacturers only use primary metals.

Metals properties are not deteriorated by recycling, thus aluminum and copper have a high recycling rate on these specific products [18]. A high recycling rate means good EoL supply chain. A good EoL supply chain relies at first on collection and sorting at deconstruction sites. The different steps of the EoL scenario are shown on the Figure 1. When cables are sorted from other metallic wastes at the first deconstruction step, it is possible to apply specific recycling scenarios, which are more efficient than mixed recycling scenarios.

However, in most cases metallic parts are mixed together at the EoL step without considering their provenance and use. When metallic wastes are mixed together, the cost-effective solution for refining use furnaces. As the metal is molten, the separation is done by using the difference of density and buoyancy (decanting methods, centrifuging, filtration, flotation, etc.) [19]. Despite the technology optimization, a fraction of metal is non recyclable [20]. Some alloying elements are lost in the process [21]. It leads to a drop of the metal quality which is akin to a down-cycling [22].

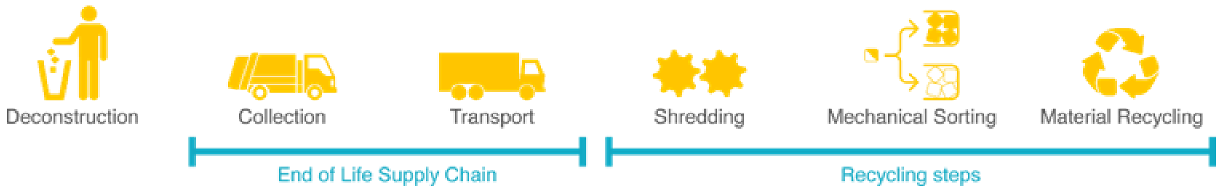


Fig. 1. Recycling main activities

2. Mechanical Recycling for cables

For aluminum cables, the aluminum core (a) is covered with a polymer thick layer (b) as illustrated in Figure 2. Additional metallic materials (c) are coaxial, integrated to reach the definition of this complex product. These cables are manufactured by extruding together all the materials that compose it.

The Table 1 shows the mass proportion of materials contained in cables. Mass proportions are extracted from MTB monitoring data of cables recycled at the plant between 2011 and 2014. Aluminum in cables represents between 35 and 55% of the total weight. Other metals are mainly steel, lead, copper, zinc. The variety of plastics contained in the sheath is even stronger than for metals: silicone rubber, Polyethylene (PE), cross-linking PE (xPE), Polychloroprene (PCP), vulcanized rubber, Ethylene Vinyl Acetate (EVA), Ethylene Propylene Rubber (EPR), flexible PVC, etc. [23]

Table 1. Composition of recycled aluminum cables at the MTB plant

	Material	Proportion
(a)	Rigid aluminium	48.5%
(b)	Plastics and rubber (PE, xPE, PVC, etc.)	40.5%
(c)	Non-ferrous metals	4.5%
(c)	Ferrous metals (steel and stainless steel)	4.0%
	Flexible aluminium	2.5%

Fig. 2. Section of multiple aluminum beams cable

Aluminum cables represent about 8% of aluminum products in Western Europe [24]. The inherent purity of aluminum used for cables justifies differentiate recycling channels to optimize processing steps and improve cost efficiency. At the EoL, the challenge concerns the separation of materials from each other. The most economical way to separate different materials rely on a smelting purification [25]. Even if the cables are complex objects composed by a multitude of materials (Table 1), it is possible to carry out a mechanical recycling without melting.

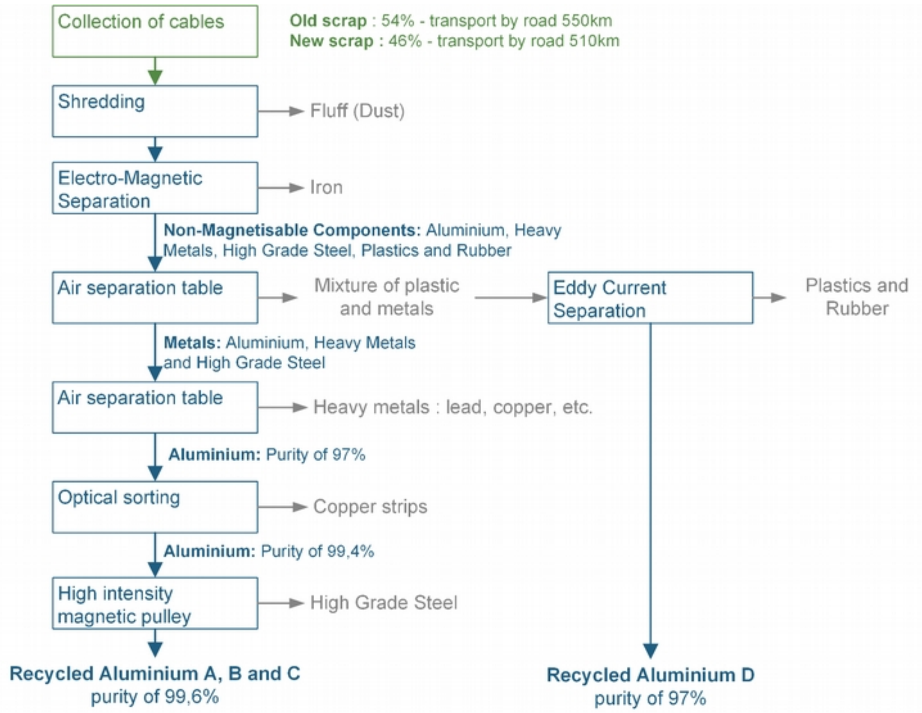


Fig. 3. MTB end-of life recycling process for aluminum cables

The alternative process for cables recycling uses only mechanical steps instead of thermal and wet separation. MTB Recycling, a recycling company located near Lyon in France, has developed for several years this kind of technology. The specific process developed by MTB and sold worldwide as cables recycling solution. Nevertheless, it reaches standard aluminum purity up to 99.6%. This performance is obtained using only mechanical separation and optical sorting processes on shredder cables (Figure 3). A similar system is in use for copper cables. Aluminum and copper from cables recycling is specially appreciated by the smelter. Its high purity makes it easy to produce a wide variability of alloys. Recycled aluminum and copper can then be used in many metallic products and not only in applications requiring alloys.

3. Recycling process environmental impact

It is thus possible to avoid a refining by melting without neglecting the quality of the out-going products. This recycling process also makes it possible to halve the impact of recycling aluminum. The Life Cycle Assessment (LCA) was conducted on aluminum recycling cables processes illustrated in figure 3. It defines the environmental evaluation perimeters. This LCA shown the impact reduction of the recycling scenarios with an environmental comparison, as shown in the Figure 4.

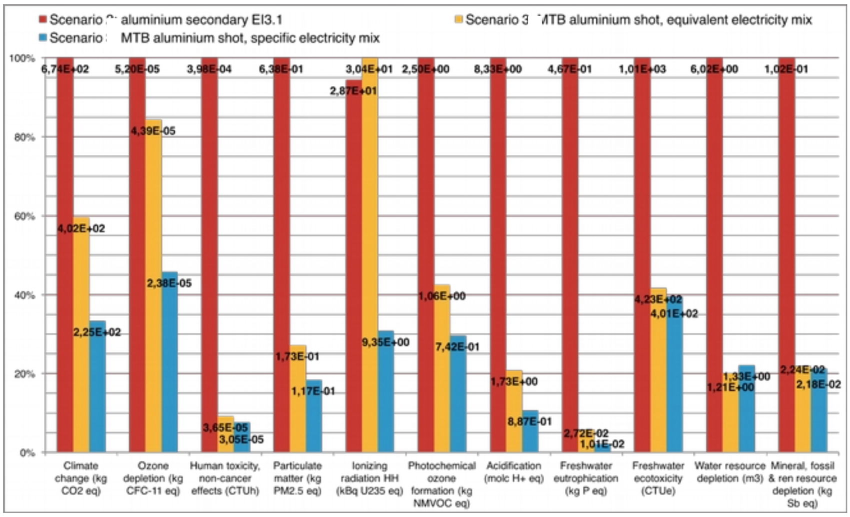


Fig. 4. Characterization of the two recycling pathways comparison using equivalent and specific electricity mix [26]

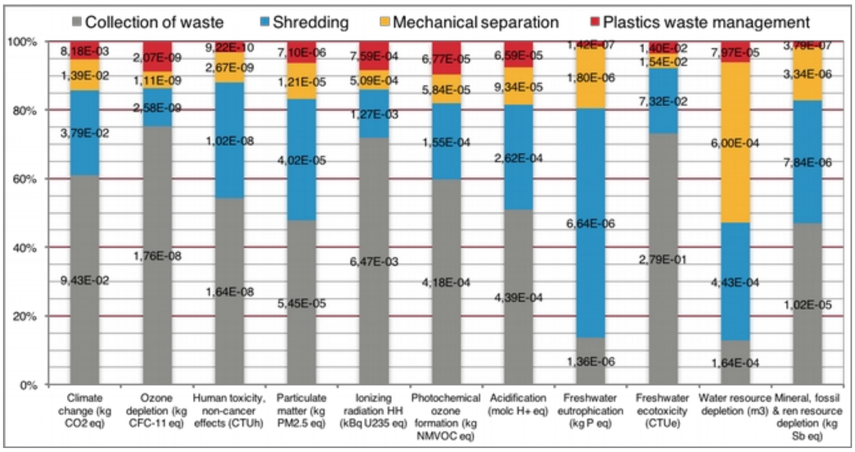


Fig. 5. Characterization of MTB recycled aluminum using specific electricity mix [26]

On the Figure 4, the results for scenario 3 are given with two set of data. The characterization is done using the equivalent electricity mix (ENTSO-E) in yellow and specific electricity mix in blue. Except for the ionizing radiation impact indicator, the impact of the MTB recycling scenario (in yellow on the Figure 4) represents between 5% and 82% of the recycling by melting scenario impact. The high electricity consumption during the shredding steps heavily contribute on this indicator. Using only mechanical separation steps can have the overall environmental impact. For the comparison of aluminum produced (specific electricity mix), the impact of scenario 3 (in blue on the Figure 4) does not exceed the impact of scenario 2. In addition, the impact of MTB recycling scenario represents between 2% and 46% of the recycling by melting impact. Thanks to MTB recycling pathway, on the set of indicators the environmental impact of recycled aluminum is divided by four.

Results from Figure 4 allows us to establish a hierarchy between environmental recycling solutions for aluminum cables. Whatever the electricity mix used by the recycling plant, the MTB mechanical recycling process is the most environmentally friendly path-way. It also demonstrates that recycling when driven without loss of quality is a relevant alternative to mining. These results also show the environmental relevance of the product centered recycling approach for cables recycling. The LCA revealed that the closed product loop option (considering aluminum cables) has lower environmental impact over the other recycling scenario using mixed aluminum scraps. This performance has already been demonstrated for aluminum cans [27] and for other materials [28].

This attractive performance hides a hot-spot, transport is the main contributor to the overall impact of this recycling solution. The Figure 5 shows the logistic predominance in MTB cables recycling scenario. On our set of indicators, transport represents more than 50% of the impact. Indeed, before reaching the treatment plant, old and new scraps have traveled 550 km on average.

The Figure 5 shows the results for the characterization of the MTB aluminum recycling pathway, with the specific renewable electric mix used by MTB. The values used for the representation are given on the figure. The results show a very strong contribution from the upstream transport for the collection of waste in the total impact of the scenario. On the set of indicators, the MTB recycling steps represents between 11.4% and 79.7% of the total impact, the rest of the impact is related to transportation. The average of the 11 indicators is equal to 36.1%, and the median is 33%.

4. Mobile recycling plant solution evaluation

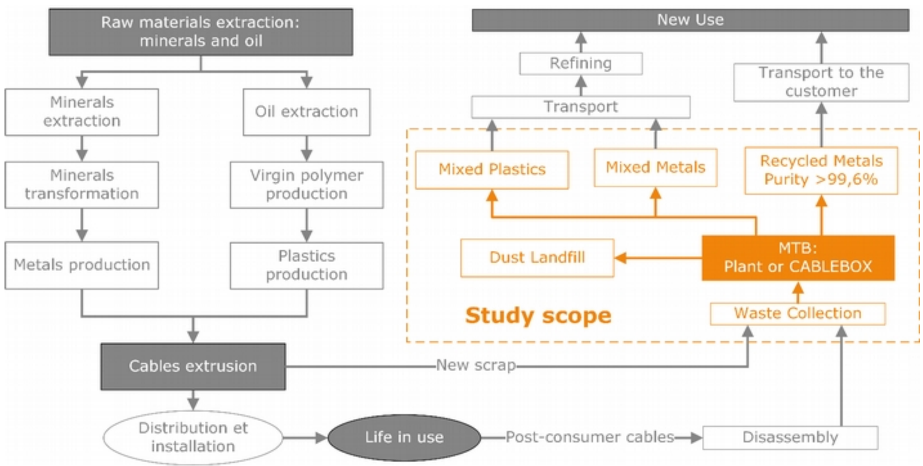
The impact of the transport guides MTB Recycling to develop a mobile factory, CABLEBOX, integrated into containers. The CABLEBOX system is not autonomous, it requires an external power source. The energy mix used for the local supply of the system depends on the location. There are no direct local emissions but only indirect emissions. The study is based on a life cycle approach, in accordance with ISO 14040/44 standards [26, 27]. The figure 6 presents the study scope used for the life cycle comparison. The boundaries include cradle to exit gate stages [32,33]. Life in use of materials in cables and new products are not included in our study scope. The study only focuses on recycling steps of metals. As shown on the Figure 7 by-products are included in environmental impacts calculation, but no environmental and economic benefit of by-products recycling is integrated into the study.

Figure 6, the orange block MTB: Plant or CABLEBOX can be defined by MTB centralized recycling plant system or CABLEBOX transportable recycling system. The boundaries are the same for the two systems. Smelting plants for refining mixed metals are well dispatched on the territory, so we assume that downstream transport is similar to the two scenarios. At the MTB plant, we have the necessary equipment to separate plastics from each other. This additional treatment line is not considered by this study. How-ever, MTB is planning to integrate all these technologies as an additional container to handle the mixed plastics outflow from CABLEBOX.

Different scenario of mobility were studied:

a. MTB Centralized Recycling Plant system, with a working time is fixed on a 250 working-day basis including 10 days of complete shutdown for maintenance. Waste collection takes place at an average distance of 535 km by truck. Their average load is 23tonnes. 700 trucks supply the recycling plant

b CABLEBOX Transportable Recycling System. The system moves to get closer to the waste production sites. The four containers of the CABLEBOX are transported on three trucks and needs 1.5 days for settling. Two



transport scenarios are evaluated: i) Scenario 1 is composed of 4 displacements made partly by lorry (2,800 km) and by cargo ship (7,100 km), ii) Scenario 2 represents 3,925 km traveled exclusively by lorry.

Fig. 6. Study scope for the cable recycling system boundaries

5. Results and discussions

The life cycle modeling was done using OpenLCA V 1.5 software and Ecoinvent V3.3 database. The economic calculations were obtained from OpenLCA. Environmental impact assessment is done using ILCD Handbook recommendations [34]. In OpenLCA ILCD 1.0.8 2016 Midpoint without long term was selected for the calculation. For environmental calculations, we only present results for the climate change indicator for this simplified environmental study. The impact factors selected from climate change is the 100-year IPCC baseline model [35].

5.1. Life Cycle Cost Assessment

The Life Cycle Cost (LCC) calculation give us the results present in the Table 2 below. In the column CBR tonnage, the values for centralized system of the waste collection, electricity consumption and working costs are given per the CABLEBOX annual tonnage (6,000 tonnes). This adaptation makes it possible to compare the results directly with the CABLEBOX system. The CABLEBOX system is presented with the 2 transport scenarios. Maintenance costs per tonne are considered similar for both systems. We do not report operating costs for reasons of trade secrecy.

Table 2. Life cycle cost assessment results for the two systems

Systems	**Centralized system**		**CABLEBOX System**	
	Annual tonnage	**CBR tonnage**	**Scenario 1**	**Scenario 2**
CABLEBOX transit	0 €	0 €	40 k€	21 k€
Waste collection	1,018 k€	398 k€	92,454 €	
Electricity consumption	293,818 €	114,773 €	68,218 €	
Working cost	600 k€	225 k€	561.6 k€	
Cost per tonne	124.5 €/t		117.5 €/t	114.6 €/t

5.2. Life Cycle Assessment

With the European electrical mix, the CABLEBOX system is far less impacted than the centralized system. The results for climate change are shown on the Figure 7. The environmental impact of the recycling system on climate change indicator is reduced by 60%. This hierarchy is true on all the impact indicators of the ILCD methodology. The choice of a transportable solution is relevant from an environmental point of view. Nevertheless, the choice of a renewable electrical power mix makes it possible to compensate the upstream logistic impact. Thus, allows the centralized system to remain competitive from an environmental point of view. We also note that the CABLEBOX transport scenarios have little influence on the climate change final impact, about 2% in the examples studied.

The Figure 8 shows the process contribution for the CABLEBOX recycling system case using scenario 1 and European electricity power mix. The electricity power required for the recycling process contributes to two thirds of the final climate change impact. Upstream logistics transport is the second-largest contributor. The CABLEBOX transport scenario represents 2% of the final climate change impact.

The same evaluation of the process contribution was made for the study of the centralized system. The results on the Figure 9 are obtained using the European electricity power mix for the centralized system. The impact of the recycling process is almost twice more impacting than the CABLEBOX system. However, the main difference is the contribution of transport, which is 5 times greater in centralized system.

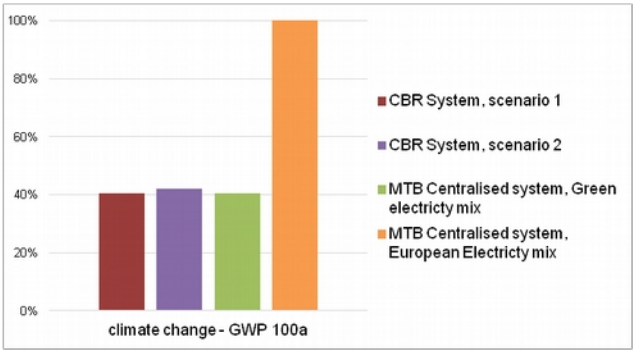


Fig. 7. Characterization of the two systems using equivalent and specific electricity mix

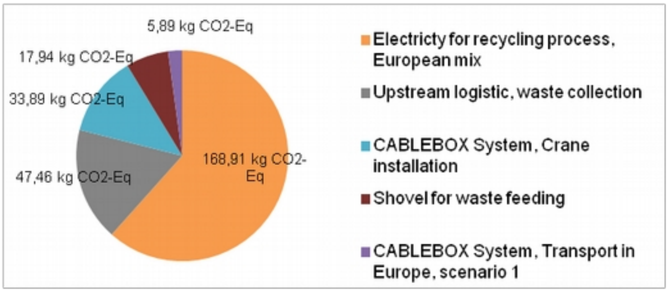


Fig. 8 Process contributions for the CABLEBOX system overall impact assessment

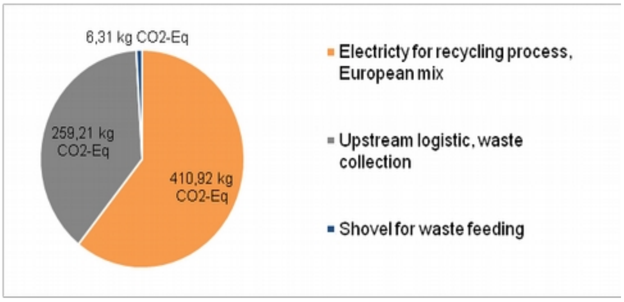


Fig. 9. Process contributions for the centralized system overall impact assessment

5.3. Discussion

In this study, we wanted to quantify the importance of transport impacts in recycling industry. Indeed, thanks to the optimization of recycling processes, the contribution of transport to the overall impact of recycled material becomes quickly prevailing. It is necessary to review the logistics flows to limit them to a minimum. However, logistic streams before and after treatment steps during the EoL scenario should be seen as a whole and not individually. The overall view could bring both the recycling plant closer to waste production sites and close to recycled material consumers. This optimization logic should bring EoL stakeholders closer from each other. Transportable recycling systems are interesting only in the case of a homogeneous distribution of producers and consumers on the territory.

For cables EoL moving the recycling plant allows environmental and economic gains. Without a complete case-by-case study, it is impossible to judge the advantage of one system over the other. However, recycling in a closed loop by integrating the recycling plant within the production plant itself will always be more competitive than a centralized recycling system far away from consumers of recycled materials. Beyond the environmental advantage, integrating the recycling plant into the production site also makes it possible to avoid the price of raw materials. In that case, only the marginal cost of recycling is integrated in the new products material cost. Containers recycling solutions cannot meet all needs. Despite this, box systems have the merit of proposing a complementary approach to centralize recycling systems.

6. Conclusion

CABLEBOX is the first integrated and transportable cable recycling solution. It is designed to be a system plug and run. This solution minimizes waste transport before recycling. Conversely, the flow rate is greatly reduced and the process does not go as far in material recovery and valorization as a centralized system. While environmental gains are indisputable regard-less of the electrical mix, the economic gains obtained remain low. We struggle with the difficulty of correlating environmental and economic benefits. Our approach reveals the difficulty of responding to the three pillars of sustainable development.

From an environmental perspective, the recycling by sector remains the most relevant. As already demonstrated for cables. Although product centered recycling solutions show good environmental performance results; they concern only specific products. We must work on the development of this approach in the coming years to ensure efficient and consistent resource use. On a case-by-case basis, solutions are possible, but the right technologies adapted to each product remain to be defined. Moreover, optimizing recycling pathway systems is long and demands powerful assessment tools such as Mass Flow Analysis (MFA), LCC and LCA [29,36,37]. The first limit of this approach, results are obtained after entry into service of processes, the investment is already made. Then manufacturers are reluctant to improve efficiency [38,39].

Therefore, it seems to be necessary to develop an effective methodology to evaluate and guide process design choices to ensure economic, environmental and social efficiency [22]. Offer to designer an assessment tool will optimize the sustainable performance of pathways. Our team is focusing our research on this issue to offer recycling engineer tools to assess recycling pathways according to technical, economic and environmental performances [40].

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